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Does Soil Testing for Fertiliser Recommendation Fall Short of a Soil Health Card?

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Abstract

Nutrient depletion and imbalanced use of fertiliser nutrients, inappropriate tillage and rain- water management practices often result in land degradation. Declining soil health contributes to climate change through loss in soil productivity, biodiversity, soil carbon, and moisture and ecosystem services. In order to address declining soil health, government of India has launched a soil health card (SHC) scheme aimed at need base use of chemical fertilisers. The paper points out the short-comings in the SHC scheme. Balanced and need base use of chemical fertilizers can be helpful in environmental protection and restoring soil health. The paper identifies potential agronomic practices and production management systems that can reduce our dependence on synthetic nutrients. Integration of soil fertility management domains with computer based QUEFT crop model has the potential of making fertiliser recommendations more domain and crop specific and less cumbersome. For soil health assessment chemical indicators must be integrated with physical and biological properties of the soils which can be predicted through reflectance spectroscopy. For assessing soil health related issues across different agro-ecoregions, there is however an urgent need for building-up more robust soil reflectance libraries.

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Introduction

Agricultural policies associated with the Green Revolution have played a dominant role in enhancing the production of chemical fertilizers for meeting the nutrient needs of crops to boost their productivity. Green Revolution era shaped agronomic research, much of which was singularly focused on use of chemical fertilizers to harness the potential of the new improved cultivars. In our zeal to enhance total production, we grossly overlooked the need for balanced use of N:P:K fertilisers and the importance of regulatory functions of soils. Subsidies on chemical fertiliser nutrients promoted not only over-use but also their imbalanced use and discouraged farmers to use bulky organic manures. Farmers have further resorted to crop residues burning to enable easy intensification of the cropping systems. As a management practice, residue burning may hasten decline in quality of soil organic matter (SOM), the major soil ingredient facilitating soil aggregation and structural stability[1–3]. Decline in SOM also reduces the ability of soils to absorb and retain soil moisture[4,5] and sustain biotic activity that make soils a life-giving entity. The extensive and elaborate matrix of soil microorganisms and other life forms are known to contribute to soil health. Soil microbes play a key role in bioremediation, contribute to agricultural productivity by modulating disease, increasing plant tolerance to abiotic stress, and nutrient cycling[6]. Any adverse effect on the regulatory soil functions (e.g. regulation of nutrient and moisture supplies, drainage congestions, soil erosion etc.) also significantly reduces productivity of soils.

National Soil Health Card (SHC) Scheme

Soil testing should lead to a better prognosis of the constraints beyond nutrients, help target management practices to alleviate constraints (chemical, physical & biological) and indicate how the soils will respond to specific management practices. The usual chemical tests of soils currently in vogue, apparently do not take us beyond fertiliser use and indicate very little about the physical and biological constraints/ properties of the soils. Also, significant differences amongst climate, soil and management, make it impossible to extrapolate the results of fertilizer recommendation from one site to others. Integrated analysis of the long-term rice-wheat yield trials conducted at 23 locations across the Indo-Gangetic plains indicated that wheat yields had not improved even after 7-23 years, while surprisingly rice yields had declined during the same periods[7]. Yield gap analysis in cereal crops, which provides a measure of untapped production capacity, have been observed to be large and highlighted by others as well[8–11]. Low productivity was linked to several lows in rainfall, fertilizer use and irrigated area[12]. However, low agricultural productivity and poverty in the eastern districts located between 78.83° and 86.13° East longitude, were observed to be in parallel with high rainfall[13]due to difficulties in managing the soil physical environment and poor resource endowments of the farmers. Several workers have pointed out that it is possible to bridge the management yield gaps through adoption of better bet practices[11,14]. Low farm productivity generally implies that the lots of the farmers can only be improved through (i) a higher support price policy (ii) a reduction in production costs, and (iii) enhanced productivity of the resources.

It appears that the innovative production management system such as “conservation agriculture” can meet the last two requirements in addition to supporting a healthy and vibrant ecosystem[15–18]. Recently, Planning Commission (Niti Aayog)[19] has also indicated that real income of the farmers have come down by 1.36% a year over the last five years. Therefore, the government will need to pursue both, the price and the production management system routes to lift the lots of the farmers. For example, Mohapatra[20] has indicated that compared with soil application, fertiliser use efficiency can be improved by 42 to 67% for different crops with drip fertilisation to enhance farm gate incomes. In pursuance, Government of India launched the National Soil Health Card Scheme (SHC) in 2015 to address the laudable concerns of soil health in the country. The scheme will monitor soil health and engage experts to help farmers in carrying out the corrective measures. In order to improve reliability of the test reports, the scheme is paying attention that the persons who carry out soil analysis and also the one involved with drafting of the recommendations for the farmer do not change hands over time for greater effectiveness of the scheme. SHC scheme has a provision to send 1% soil samples to State referral laboratories for validation of the soil test reports. So far, 25.5 million samples have been collected and more than 95% of these have been analysed.

The efficacy of the SHC depends on a three-step process, namely (i) collection of representative soil samples and farmers' inputs about their fields, (ii) reliable chemical analysis of the soil samples in a timely manner, and (iii) development of soil test based recommendations, duly recognising any other soil constraint such as drainage congestion, soil depths, poor soil moisture retention, rolling landscapes, soil erosion, poor biotic activity or soil borne diseases/ pests etc.[21,22]. Any dislocation or delay in the three-step process could easily render the SHC service ineffective. Currently, representative soil samples are collected in a grid pattern, wherein a sample is drawn from each 2.5 and 10 ha of irrigated and rain-fed farms, respectively. The criteria is arbitrary in absence of information on spatial variability on the farms and whether sample represents a specific resource management domain (RMD). Soil samples received in the laboratory lack geo-tags. Farmers' are not required to provide their indigenous knowledge on what ails their soils and how farm soils respond to management practices adopted in specific production systems. This makes prognosis of the farm problems very difficult based on chemical tests alone. Prescription is likely to be as good, as the diagnosis. The short-circuited scheme (irrigation water quality not considered at all) appears to be oriented just to contain the workload in the 3-year cycle of repeat analytical work. There is a general concern on the infrastructure quality and the trained manpower in some of the soil testing laboratories. The SHC scheme has little research back stopping for reducing the burden of reliable and representative soil sample collections, analytical and other work associated with testing of large number of soil samples. Consequently, soil-testing laboratories are overcrowded with large sample inventories and busy with preparation of fertiliser recommendations ahead of each planting season.

Soils are the keystone of healthy and vibrant ecosystems, providing physical, chemical, and biological substrates and functions necessary to support life but are under constant threat from heavy use, poor management and changing climate. In the on-going National Soil Health Card Scheme (SHC), report cards provide chemical analysis on status of macro- (N,P,K,S) and micro-nutrients (Fe, Zn, Cu, Mn and /B) besides values for electrical conductivity (EC), pH and soil organic carbon (SOC). The soil test based fertiliser recommendations in SHC are based on either the area-general fertiliser recommendations of the state governments or on the basis of targeted yield equations developed by the soil test crop response scheme (STCR) of the Indian Council of Agricultural Research (ICAR).

SHC scheme in its present form does not take us beyond fertiliser recommendations, and does not capture or monitor soil functions which make soils a living system, providing a range of eco-services for mankind (e.g. filtration of water, aquifer recharge, preventing nitrate pollution of drinking water, water retention and supplies and climate change etc.). SHC scheme also does not consider the physical and biological attributes of soils, which can also influence the use efficiency of resource inputs in crop production, both positively and negatively. It provides little information on the impact of specific nutrient management practices on soil health. Thus the SHC scheme misses the vital connection to soil health vis-a-vis multiple ecosystem services provided by soils. It is for these reasons, enhancing total food production without due diligence on soil degradation processes and ecosystem services, has been a fundamental flaw of the Indian strategy for food security under the new realities of climate change. Excessive dependence on chemical fertiliser nutrient based approach for maintaining soil fertility, without adequate attention to management of soil organic carbon and rain-water has only contributed to continued and accelerated soil degradation in the Indian summer monsoon season (hot summers: April- June: monsoon season: July –September). Summer deep plowing, bare fallows and crop residue burning all together reduce the capacity of the soils to absorb rainwater and convert it in usable soil moisture by crop plants. As a consequence, natural resources are now showing multiple signs of fatigue and decline[17,23].

Fertiliser Use and soil Health

Generally farmers apply P and K fertiliser nutrients as basal application along with a starter dose of N at the time of crop seeding. The balance of N fertiliser dose is subsequently top-dressed in 2-3 splits or variably applied "on-the-go" in response to proximal crop sensing using chlorophyll meter, GreenSeeker, Yara N and Crop Circle sensors[24–27]. In terms of the effect on soil health and crop production there is no conflict between mineral fertilizers and organic nutrient sources; quite the contrary, their use is complimentary[28]. Applied N is generally accepted to enhance biomass and hence soil organic matter[29,30] which is subsequently decomposed[31] in presence of synthetic N. This makes the role of applied N in organic matter decomposition, little controversial. But on the whole, long term experiments from all over the world have pointed out that adequate and balanced use of mineral fertilizers, generally result in an increase in soil organic matter (SOM) and better biological life in fertilised than non-fertilised plots[32–34]. Given the fundamental coupling of microbial C and N cycle, dominant occurrence of both elements in SOM, and their close correlation to mineralization, practices that lead to loss of soil organic C also have serious implications on soil nitrogen. Considerable evidence from ^{15}N-tracer investigations indicates that plant uptake is generally greater from native soil N than from N applied via fertilizers[35]. Thus, native soil N dictates the efficiency of applied fertilizer N as well as the quantity of N lost from the soil-plant system. This has implications for soil functioning and crop productivity. While it is considered that the availability of carbon substrate is normally the primary limiting factor on microbial activity, in soils, this is not necessarily the case, and there is accumulating evidence that soil microbes may frequently be N limited[36,37]. Thus, nutrients, land-use and management practices act as controlling inputs for the processes within soil system and hence of the soil health. If there are no additions of nutrients to replace those lost through crop offtake and other processes, the capacity of the soil ecosystem to deliver production and other services declines, and so does the health of the soil[37]. The impact of nutrient additions on the assemblages of mineral, soil organic matter constituents and soil organisms is complex. This is because the organisms involved in organic matter decomposition, nutrient cycling and soil structure formation are ultimately themselves becoming the primary or secondary constituents of soil organic matter[16]. This soil carbon sponge however, is of great significance for its influence on soil aggregation, water infiltration, water retention, access to essential nutrients, and support a diverse range of microbial processes. Soil organisms respond sensitively to land management practices and climate and correlate well with beneficial soil and ecosystem functions[38].

Strategy for Reducing Dependence on Chemical Fertilisers

The Prime Minister of India has urged that our dependence on chemical nutrient fertilisers be reduced to half in the coming years to protect environment and improve soil health. In spite the fact that this is a laudable objective and a challenge for agricultural researchers, developmental agencies and the farmers, it is yet to ignite a debate on how this objective can be achieved sooner than later. This challenge would call for a major shift away from the singular focus on chemical fertilisers to more of the biological approaches to sustain and enhance the current levels of crop production. To save on fertilisers, we need to (a) identify potential agronomic practices that reduce use of synthetic nutrients and (b) identify production management systems having the targeted effect. The enunciated policy statement implies that we immediately promote the adoption of agronomic practices such as (i) inclusion of legumes in the cropping systems, (ii) conjunctive use of chemical fertiliser and organics, (iii) rely on nutrient recycling with cropping pattern differing in rooting pattern, (iv) application of beneficial symbiotic microbial associations, (v) deploy in situ / ex situ composting techniques to improve biotic activity in the soils, (vi) increase botanical N fixation, (vii) raise green manuring crops,(viii) use microbial inoculants to improve nutrient access in soils (arbuscular mycorrhiza and P solubilizing bacteria) and (ix) promote rational use of nutrients in cropping systems, etc.. The production management system strategy requires promoting the adoption of (soil, water, and crop management strategies) that improve resource use efficiency and build soil organic carbon. Conservation agriculture (CA) is one such innovative production management system, which is close to organic farming. CA allows use of agrochemicals and its yield potential is hardly debatable, unlike the organic farming. CA as a production management system has the targeted effect in reducing the use of synthetic fertilisers through attributes such as: (i) tillage practices that reduce the rate of SOM decomposition, runoff and soil erosion (avoidance of summer deep plowing), and conserve soil moisture etc. to improve soil health (ii) enable seeding in excessively moist (surface seeding) or in dry soils (dry seeding) and inclusion of high biomass producing crops, (iii) residue retention and brown manuring, (iv) switch from monoculture to rotation cropping and annual to perennial crops, (v) reduce fallowing during rainy season (vi) avoids sudden land use changes[39–41], and (vii) adoption of agroforestry systems etc.. Soil organic matter content and carbon levels are central to the ability of soil to provide essential services to society. Since soils have the potential to help mitigate climate change: it should be part of the solution, not part of the problem[42]. On the scales, it appears that to be able to move in the 'implied direction', it would be even more important that we must re-orient our production management systems such that they begin to promote and enhance agroecosystems health under new realities of climate change.

Globally, research outputs have clearly indicated that inclusion of M^3 research namely, soil Organic Matter, soil Microbes and soil Moisture retention, is critical in arresting and reversing soil degradation processes. Most researchers are in agreement that the M^3 soil attributes enhance soil productivity, improve nutrient and water use efficiency, reduce production costs and significantly benefits the environment. There is an urgent need to move away from the traditional tilled agriculture (having many conflicting and unsustainable practices) to production management system such as the conservation agriculture (CA). CA consists of four broad intertwined management practices: (1) drastic reduction in soil disturbance, (2) maintenance of a continuous vegetative soil cover; (3) direct sowing; and (4) sound crop rotations. CA based production systems mimics natural agroecosystems and hence would result in numerous environmental benefits such as decreased soil erosion and water loss due to runoff, decreased carbon dioxide emissions and higher carbon sequestration, OM build-up, efficient nutrient cycling, reduced fuel consumption, increased water productivity, less flooding, and recharging of underground aquifers[15,43], reduce compaction in the subsoil, and cracking in Vertisols. No-till agriculture with residue retention on soil surface has been found more carbon efficient and helpful in producing more at less cost and improve soil health in the process[13,44]. It is our strong belief that conservation agriculture principles can and must form an important component of the national strategy to produce more food, sustainably at lower costs, improve environmental quality and preserve natural resources[15,18]. Adding more chemical inputs to the soil, without addressing other parallel soil health concerns is bound to prove futile and is only expected to further aggravate the widening N:P:K ratios and inefficient use of fertiliser nutrients.

Resource Management Domain Concept for Reducing Analytical Workload in the Labs

Agricultural research, based on agro-climatic zone, was initiated by ICAR in 1979 with an objective to generate location specific data for identification of the major problems limiting agricultural growth. Using the criteria of soils, physiography, bio-climate (climate, crops, and vegetation) and length of the growing season, ICAR delineated the country into 20 agro-ecoregions (AER) and 60 agro-eco-sub-regions (AESR). These criteria carved out homogenous regions for their growth potential, but did not reflect on the socio-economic endowments, market support and service sector in agricultural development. The AER concept also ignored the fact that introduction of irrigation water alleviates a major constraint for crop production and in fact provides opportunities for diversification of agriculture. In order to further refine the concept, ICAR introduced the concept of Production System Research (PSR), which is not only analogous to AER and geographical approach but goes beyond both of them. PSR concept integrates all the system components for determining productivity and profitability of the system. A total of 126 agro-climatic, NARP zones were earlier delineated in the country, based on ecological parameters like topography, rainfall pattern, soil types, temperature, cropping pattern and water availability which influence the type of vegetation[45]. Later on the ICAR bundled the NARP Agro-climatic zones into 15 prioritised production systems[46] under the 5 agro-ecosystems (Irrigated, Rainfed, Hill and Mountains, Coastal and Arid ecosystems). Within each production system, homogenous resource management domains (e.g. soil fertility) can be further delineated such that each land unit is having similar production constraints and needed similar management.

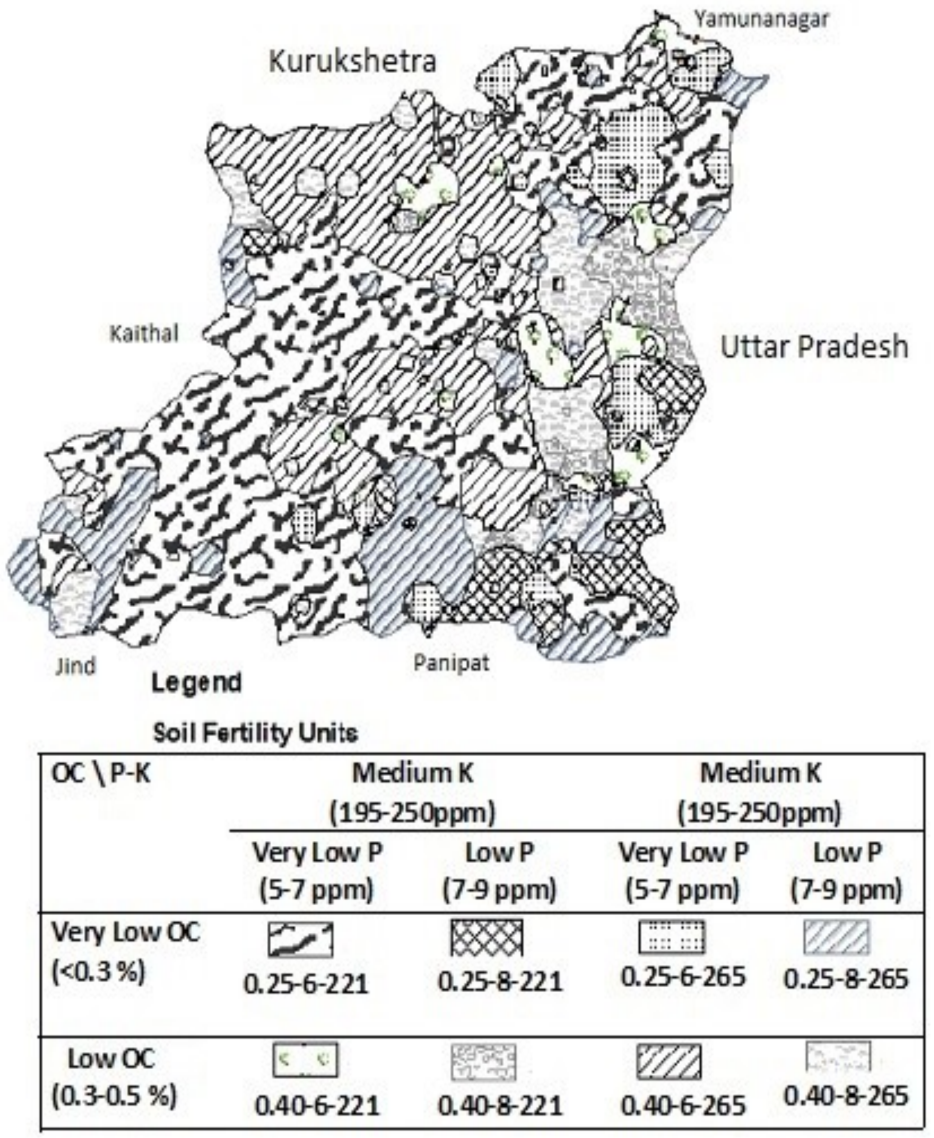
Managing the natural resource base and sustaining agriculture require land based solutions. To meet these stated objectives, researchers have focused on the integration of biophysical and socioeconomic parameters to characterize land management units, also known as resource management domains / zones[47–50] for better resource management and sustainable agricultural production. Resource management domain/ unit is a homogenous land unit having similar constraints and need similar management approach for a specific land use. The concept of homogenous resource management units/ zones/ domains has progressed through many stages and has now found its way into precision farming for site-specific crop management[51]. This school became very popular when field comparisons of uniform versus variable fertiliser applications showed that there was considerable variability at scales finer than soil mapping units[52].

The way forward seems that all exiting spatially distributed point chemical test patterns of N, P and K etc. be used for development of a georeferenced soil fertility framework. Using all the existing chemical soil test values obtained from analysis of spatially distributed samples in the state soil testing lab, an unsupervised classification method of multivariate clustering was used to delineate eight homogeneous soil fertility management zones[53] as illustrated in figure (1). Farmers primarily practice rice–wheat/Indian-mustard cropping systems in Karnal, Haryana. The mean values of N/OC, P and K combinations for each of the eight delineated homogenous fertility management zones are given in tabular form below figure (1). Using the mean nutrient values in the QUEFTS (Quantitative Evaluation of Fertility on Tropical Soils) crop model, enables one to compute domain and crop-specific fertiliser recommendations[53-55].

The RMD frame-work allows cost-effective procedures for soil sample acquisition, and drastically reduces analytical work, besides enabling researchers to incorporate significant factors that regulate the supply of nutrients and hence fertiliser recommendations. Resource domains having a specific N, P and K combinations allows for real-time fertiliser recommendations[26,53–58] for different cropping systems using different management practices (conventional or zero tillage). Computer aided modelling approaches uses the inherent nutrient supplying capacity of the soils (omission plot data and nutrient interactions) but may also consider the effects of tillage, residues and soil management options in regulating the supply nutrients vis-a-vis need for additional fertiliser. The resource management domain concept will also enable adoption and use of the customised fertiliser grades in the specific fertility domains. At present, SHC report does not consider effect of poor irrigation water quality, known to limit crop production and degrade soil health. The enabling concept of resource management domains will link the problem of poor quality ground waters, with soil fertility/ SHCs and also recommend corrective measures. The customised fertiliser approach will make recommendations more realistic and save on costly fertiliser nutrients and improve soil health through use of balanced fertilisers.

Soil Health Assessment

For agriculture to remain productive, it has to return to its roots and rediscover the importance of healthy soils. The two crucial characteristics of a healthy soil include rich diversity of its biota and the high soil organic matter content[59]. Attempts to quantify soil health generally involve estimation of physical, chemical and biological properties and also an assessment of large scale feature of environment such as bioclimate[60]. Soil fertility, water quality, erosion resistance and climate mitigation are considered as very important ecosystem services[61] which relate to soil organic matter (SOM). The SOM integrates the concept of soil health and ecosystem services and also facilitates the impact assessment of management practices on C build up vis-a-vis on sustainability of the ecosystem services. Comprehensive Assessment of Soil Health (CASH) approach of the Cornell University places primary emphasis on the identification of specific soil constraints in agroecosystems, thereby aiding in the selection of land management solutions to increase land productivity and minimize environmental impact[22,62]. The CASH approach measures 15 physical, biological, and chemical soil indicators which relate to relevant soil functions and are interpreted through three types of scoring functions (more is better, less is better and an optima function). Knowledge of the relationship between indicators and the relevant scoring functions enable one to translate measured indicator values into a unit-less score. Recently it has suggested[63] that development of



Legend

Soil Fertility Units

OC \ P-K	Medium K (195-250ppm)		Medium K (195-250ppm)	
	Very Low P (5-7 ppm)	Low P (7-9 ppm)	Very Low P (5-7 ppm)	Low P (7-9 ppm)
Very Low OC (<0.3 %)	▰ 0.25-6-221	▩ 0.25-8-221	▦ 0.25-6-265	▨ 0.25-8-265
Low OC (0.3-0.5 %)	▢ 0.40-6-221	░ 0.40-8-221	▨ 0.40-6-265	░ 0.40-8-265

Figure 1. Resource management domains for soil fertility delineated for the Karnal District, Haryana, India

region-specific scoring functions may be appropriate after more complete regional soil health data analyses. According to them, simplified soil health tests can be based on the use of at least four indicators namely the active carbon, penetration resistance, respiration rate and water stable aggregates.

Remote Sensing for Soil Health Assessments

Remote sensing applications in agriculture are generally classified according to the type of platforms for the sensor (satellite, drones, tractor mounted and ground based). The associated imaging systems of the sensors are differentiated based on the altitude of the platform, spatial resolution of the image, and the minimum return frequency for sequential imaging of temporal patterns in soil or plant characteristics. Improvements in spatial resolution, improves the homogeneity of soil or crop characteristics due to decrease in pixel size. Vigorous above-ground crop stands, invariably supported by a profuse root system in the soil below surface, reflects on health of the soils. Crop performance can be measured using remotely sensed NDVI (Normalized Difference Vegetation Index) data on a large scale. A low NDVI may reflect to several soil conditions (poor drainage, secondary salinization, soil compaction, shallow soil depths and low moisture and nutrient deficiencies etc.) that limit plant growth. NDVI images enable us to map the combined effect of several soil health indicators besides isolating slick/ hot spots constraining crop growth.

Recent researches[51,63-67] have indicated that near-infrared reflectance spectroscopy and Vis-near-infrared reflectance (VNIR) spectroscopy can reliably predict/ estimate several chemical, physical and biological indicators of soil health[65-71]such as : soil water content, clay, sand, organic C (fractions), inorganic C, TOC or SOM, total C, C/N, CEC, exchangeable Ca and Mg, total N, pH, total concentration of potential pollutant metals/metalloids (As, Cd, Hg and Pb), enzyme activities, biomass C, and C and N mineralization, crop yield and biomass. CASH scores together with remote sensing techniques provide a better basis for quick dynamic fertiliser recommendations and assessment and management of the soil health. Soil health related issues across different agro-ecoregions however continues to be a subject of intense research for building up more robust reflectance libraries**.**

Summary

Conventional chemical soil testing approach provides information about amendment needs and fertiliser doses for replenishment of plant nutrients depleted through crop production, leaching and soil loss. This approach has proved useful in increasing agricultural production, but its sole focus on fertilizer recommendation, ignores the physical and biological environment of the soils which also significantly influence crop production. The inadequacy of the soil fertility recommendations spurred developments for a more comprehensive assessment of soil health, based on the triad of physical, biological, and chemical properties, which is more sensitive to land management practices and reportedly better correlated to ecosystem processes. Remote sensing techniques map the combined effect of several soil health indicators over larger areas besides identifying areas where soil properties (physical/ chemical/ biological) are becoming growth limiting factor. Soil fertility management domains when integrated with high resolution soil health assessments can allow us to map the state of soil health on a larger scale, and reduce soil testing costs and accelerate farm advisory services.

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